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Model studies: Impact of Intentional Contaminations and Effectiveness of Employing EWS in a Drinking Water Supply System

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Titel
Model studies: Impact of Intentional Contaminations and Effectiveness of Employing EWS in a Drinking Water Supply System

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Preface

Het onderhavige is één hoofdstuk afkomstig uit het rapport "Early warning monitoring in the drinking water sector" (BTO 2005.009) dat in opdracht van de American Water Works Association Research Foundation (AwwaRF) is opgesteld. Een deel van de resultaten uit dit rapport zijn door Joep van den Broeke en George Mesman gepresenteerd in het overleg van het Deskundigenplatform NBC op 14 oktober 2004 te Bilthoven, en deze rapportage omvat deze resultaten met daarbij extra achtergrondinformatie en een meer gedetailleerde bespreken van de uitgevoerde berekeningen.

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1 Introduction

In 2001 Kiwa and AwwaRF agreed on a project that would deal with the topics of early warning systems and drinking water security. During a common workshop, held in 2002, the goals for this project were defined as follows: to identify and evaluate innovative approaches to detect chemical parameters in drinking water in the distribution network. Hazardous compounds due to both accidental contamination (e.g. breaching of pipes) and deliberate sabotage actions were to be taken into account.

The activities that were executed as part of this project were:

1. identification of chemical/microbial contaminants, relevant for the distribution network;
2. description of technical solutions and calculation of the degree of protection of the distribution network;
3. recommendations for further testing of promising detection techniques.

Initially, a fourth objective was formulated: development of test protocols and (if possible) evaluate performance of laboratory or field tests for two or three of the most promising technologies. However, this objective has since been placed in a separate project.

The study described in this report was performed as part of this Kiwa-AwwaRF collaboration project and dealt with assessing of the impact on drinking water quality of contaminants in the distributionsystems and with optimal placement of early warning systems in the distribution network. The results of this study were previously reported in Kiwa report BTO 2005.009. This report contains only the chapter out of BTO 2005.009 that deals with the hydraulic modelling studies. The contents of this report and chapter 3 in BTO 2005.009 are identical.

2 Model studies: Impact of Intentional Contaminations and Effectiveness of Employing EWS in a Drinking Water Supply System

The following chapter focuses on predicting the effects of attacks against the distribution network. Hydrodynamic modelling software was used to determine how a toxic substance would spread through the distribution network and to indicate a relationship between the number of installed EWS and the impact of the terrorist attack.

An attack against the drinking water network is defined as the injection into the network of a toxic substance or a pathogen at any point in the network, i.e. this could be done from a home or at a central reservoir or at a pumping station. The following provides an indication of how this could be modelled in a water mains system calculation model and how the toxic substance would spread through the network. This chapter is divided into two separate parts. The first part describes the spread of a contaminant in the network of a Dutch town (referred to as town A) and makes an estimate of the number of people affected by the contaminant. The second part describes calculations for a second Dutch town (referred to as B), where the impact of a contamination and the requirements for an effective EWS were assessed.

2.1 Spread of a contaminant through the drinking water supply of town A: a model study

2.1.1 Description of the model

Using the hydrodynamic modelling software suite ALEID, the contamination of the drinking water supply of the Dutch town A with contaminant 'X' was simulated. The supply network of town A has been reduced to a model in which all pipes are incorporated. Such a model is known as a 'one on one' model. ALEID is a software suite based on EPANET, as far as calculations are concerned, with a Kiwa designed interface.

The distribution area of A and the surrounding municipalities is part of a larger supply area. In the model most of the surrounding municipalities have been disregarded, as the hydraulic connections between Town A and these municipalities are limited. Besides the city of A, a small part of a town to the west and the supply in the direction of two municipalities in the east were incorporated (figure 2.1). The entire distribution area is fed by a single pumping station which is located to the west of town A. Furthermore, the area contains two reservoirs, which store water for later resupply, namely the "A water tower" and a lower reservoir. The entire distribution area is densely populated and covered with build-up areas.

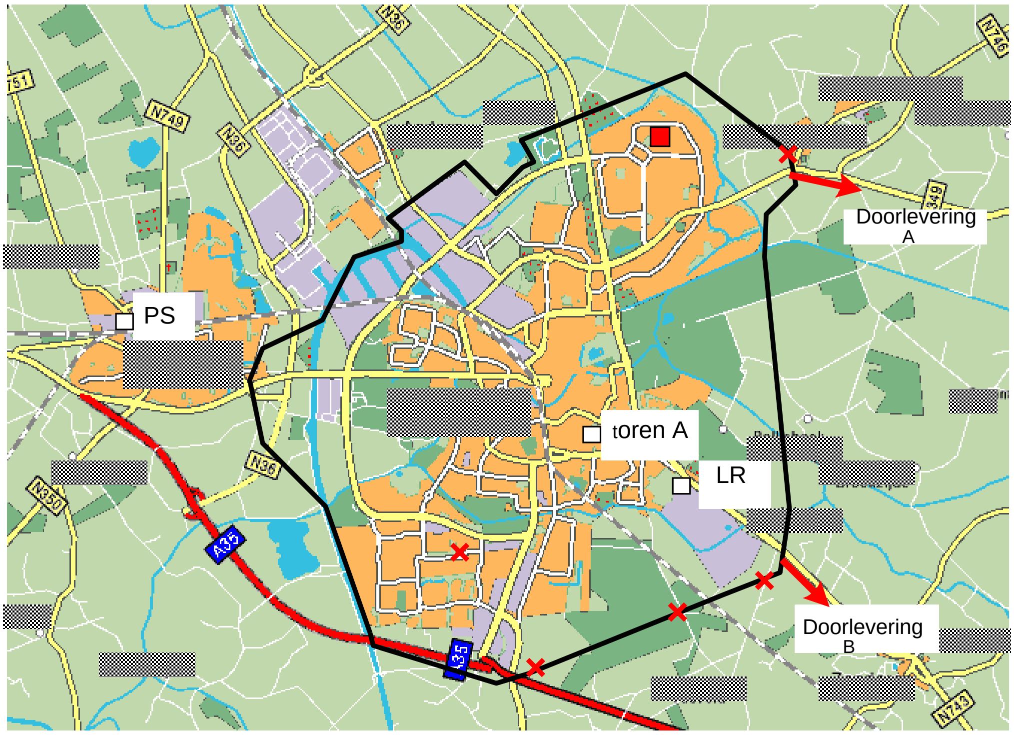


Figure 2.1: The distribution area of A and its surroundings. PS = pumping station, toren A = the water tower, LR = lower reservoir, doorlevering = 'supply in the direction of'.

The model of this distribution area has been compiled by Vitens, the water supply company responsible for this area. The area has a total of approximately 71,000 inhabitants. Figure 2.2 depicts the model of the network in town A, the different colours and thickness of the lines signifying the diameter of the pipes. The model contains all pipes present in supply network of A. Furthermore, water consumption has been recorded on a yearly basis and is used in the model to calculate consumption at any point in time. This includes water consumption of industries and other large users. However, the model only explicitly shows the water used by small consumers (households).

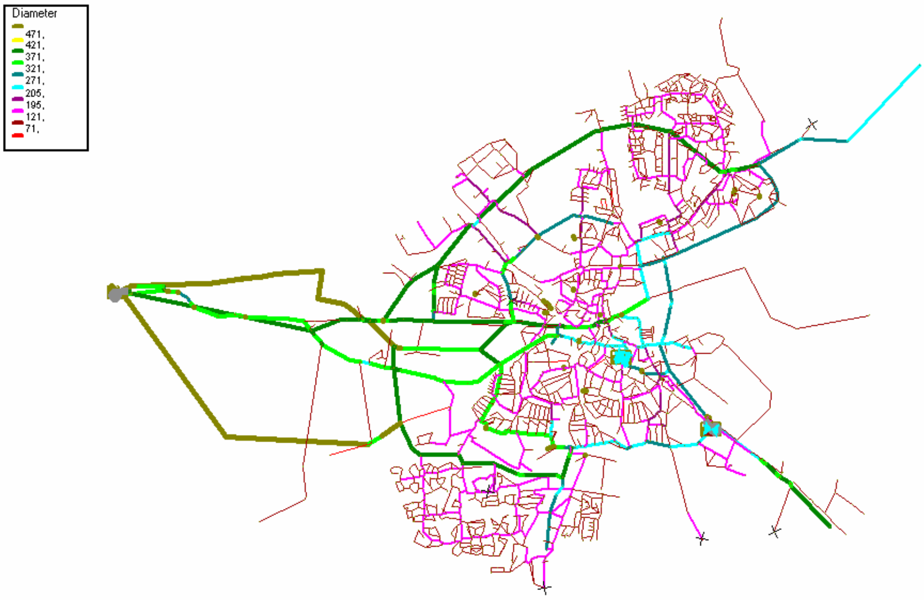


Figure 2.2: ALEID distribution area model for town A.

In order to calculate the spread of a contaminant throughout the network, the model has been expanded with the possibility to dose contaminant 'X' in mg/L concentrations at any location in the model according to a predetermined pattern. The dosed contaminant is considered to be conservative in the supply system, meaning it is assumed that no decomposition or interaction with the pipes, sediments or biofilm will take place. Therefore, the concentrations will solely change due to splitting and merging of water flows and due to operational parameters and water consumption in the model.

To limit the number of calculations performed, 6 points of introduction were chosen and the effects of the introduction of a single concentration at a single time during the day per point of introduction was performed. Results following introduction of a contaminant at a different concentration can be directly deduced from the results of the performed calculations, as long as the compounds considered are conservative.

Boundary conditions
The simulation was used to analyse the consequences of introducing the following amount of contaminant:
100,000,000 mg = 100,000 g = 100 kg

Introduction:
The contaminant is introduced during the seventh hour (6:00 hr to 7:00 hr) at a concentration of 50,000 mg/L contained in 2000 L of fluid, thus at 2000 L/hr. For generalisation of the results, 50,000 mg/L is also defined as C_0. All concentrations calculated (C) will be represented in absolute values as well as relative values ($C/C_0 = c$), which indicates how much the contaminant has been diluted.

Points of introduction:
1. Directly after the pumping station feeding the entire supply area
2. In a large supply main
3. In a private home I
4. In a private home II
5. In the water tower
6. In the lower reservoir

Time span simulated:
The ideally simulated time span is the time required to have the contaminant disappear completely from the supply system. However, when the contaminant reaches one of the reservoirs, this would require a simulated time span of over 500 hours. After some preliminary calculations this was deemed impractical, and a time span of 120 hours was decided upon. During these 120 hours the concentration in the reservoirs is reduced significantly, and the further course of the spread of the contaminant in the reservoirs and the network can be estimated fairly well, without the need for further calculations. During the simulation the concentrations were calculated every 10 minutes for the entire 120 hour time span, however the reporting interval was set at 30 minutes. At this reporting interval peak concentrations are in general still visible while the calculation can be completed within an acceptable time. When using a longer interval, peak concentrations will not be recorded at a large number of nodes in the system, while a shorter interval will require too much calculation and analysis time.

Essential data obtained from the simulation
At each node in the model the concentration of contaminant 'X' is calculated for each simulated point in time. These data are then exported for each reported point in time. In this model, under these conditions, the output generated per scenario is a listing of the concentrations at 3300 nodes with a 30 minute interval over a period of 120 hours, a total of 792,000 concentrations. These results are further processed using a spreadsheet programme, which allows the coupling of these data with the consumption and number of people connected at each node.

1.1.2 Results of the simulations

The results of the calculations have been summarised in figures, which depict the maximum concentrations observed during the 120 hour simulations. The concentration levels are indicated as follows:

- Maximum concentration at the node < 0.1 mg/L (blue) ($C/C_0 < 2\ 10^{-6}$)
- Maximum concentration at the node 0.1 < conc. < 2 mg/L (green) ($2\ 10^{-6} < C/C_0 < 4\ 10^{-5}$)
- Maximum concentration at the node 2 < conc. < 175 mg/L (yellow) ($4\ 10^{-5} < C/C_0 < 4\ 10^{-3}$)
- Maximum concentration at the node > 175 mg/L (red) ($C/C_0 > 4\ 10^{-3}$)

The point in time at which the maximum concentration is reached is known from the data output but is not taken into account in the representation in the figures.

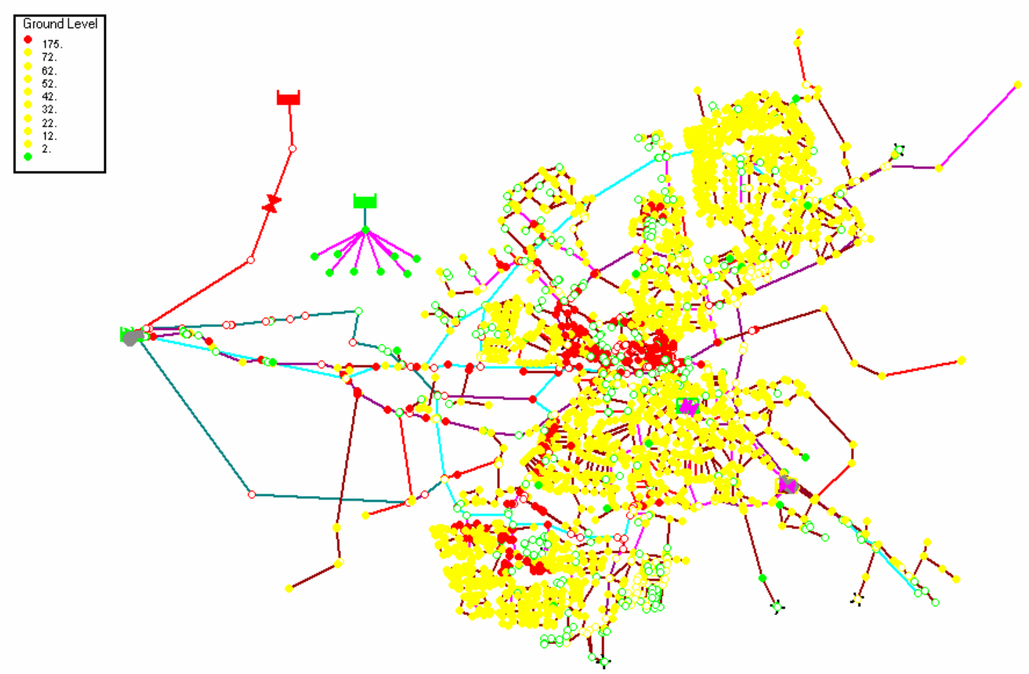


Figure 2.3: Calculated maximum concentrations when introducing a contaminant at the pumping station, reporting interval 30 minutes. The legend heading ground level should be replaced by concentration.

The concentrations calculated over the entire time span are available per node in the output of the simulation. An example of the changing concentration levels at two nodes is depicted in figure 2.4. The node THBW0 is situated on the supply main between the pumping station and A, and node G00008MV is situated in the eastern part of A. The high peak concentration at THBW0, directly after the pumping station, is lowered and spread out over a longer time period when travelling through the network (G0008MV).

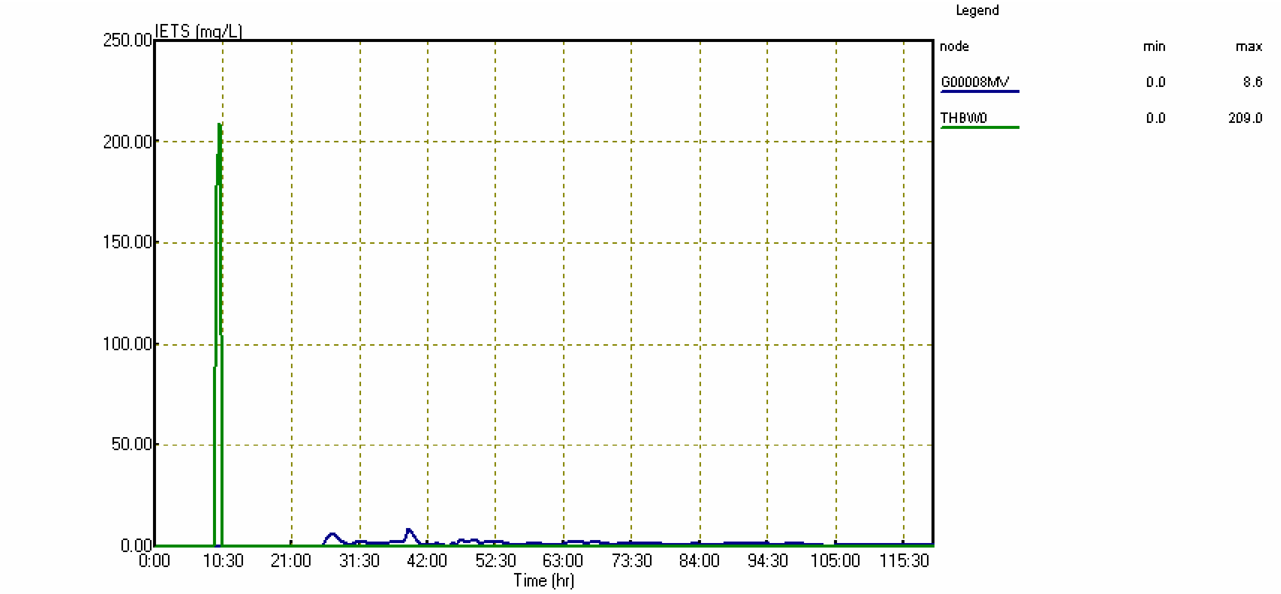


Figure 2.4: Calculated concentrations of 'X' at two nodes in the model of A. Minimum and maximum concentrations 'X' at these nodes are given in the legend.

To show the difference between using a 10 or a 30 minute reporting interval, figure 2.5 shows the results of introducing contaminant 'X' under exactly the same conditions as those for the calculations that resulted in figure 2.3. The only difference is the use of the reporting interval of 10 minutes to generate the data behind figure 2.5.

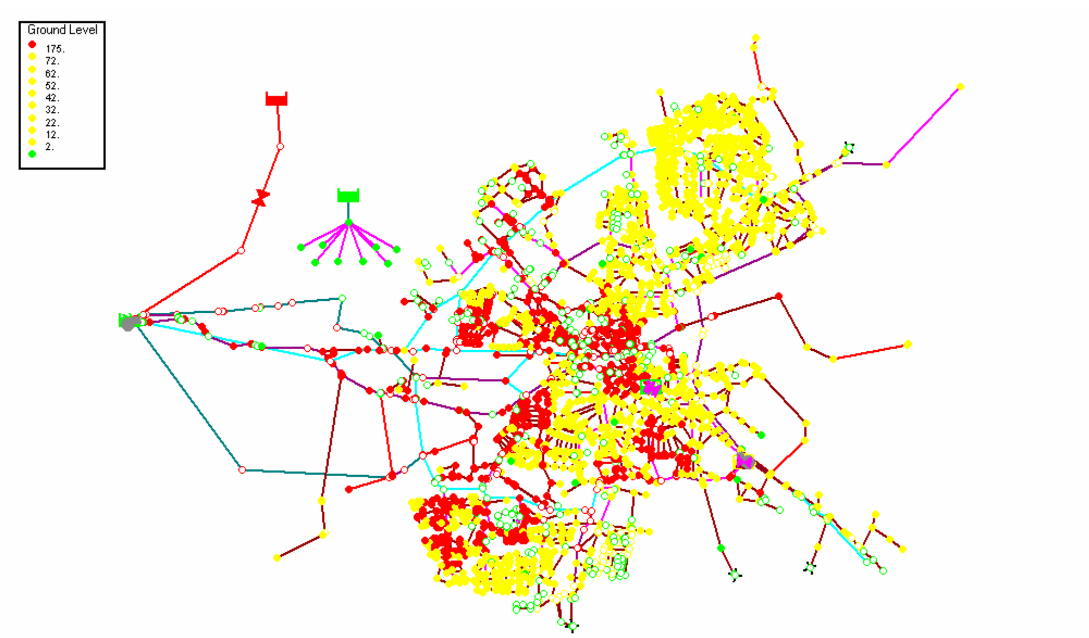


Figure 2.5: Calculated maximum concentrations when introducing a contaminant at the pumping station, reporting interval 10 minutes. The legend heading ground level should be replaced by concentration.

Figure 2.5 clearly shows that the number of red nodes, thus nodes with maximum concentrations exceeding 175 mg/L ($C/C_0 > 4\ 10^{-3}$), is higher than with the 30 minute interval used to generate figure 2.3. This is caused by the fact that with the 30 minute interval a larger number of peaks will remain undetected as they pass the node between reporting intervals. Therefore, the use of the 10 minute interval is more informative, however, due to restrictions in computing capabilities it was not possible to use the 10 minute reporting interval for all the studies performed. Therefore, it was decided to use the 30 minute reporting interval instead. The overall results are comparable, but peak concentrations will on average be lower in comparison with a dataset generated with the 10 minute interval.

Figure 2.6 shows the calculated concentrations for scenario 2, where introduction of 'X' takes place in a large supply main between the pumping station and town A itself. It is shown that part of the distribution area will not be affected by the contaminated water. Furthermore, in the northeast of the distribution area concentrations remain low, i.e. below 2 mg/L ($C/C_0 < 4\ 10^{-5}$), which is caused by the fact that the contaminant reaches these nodes mainly through the reservoirs, where it is strongly diluted.

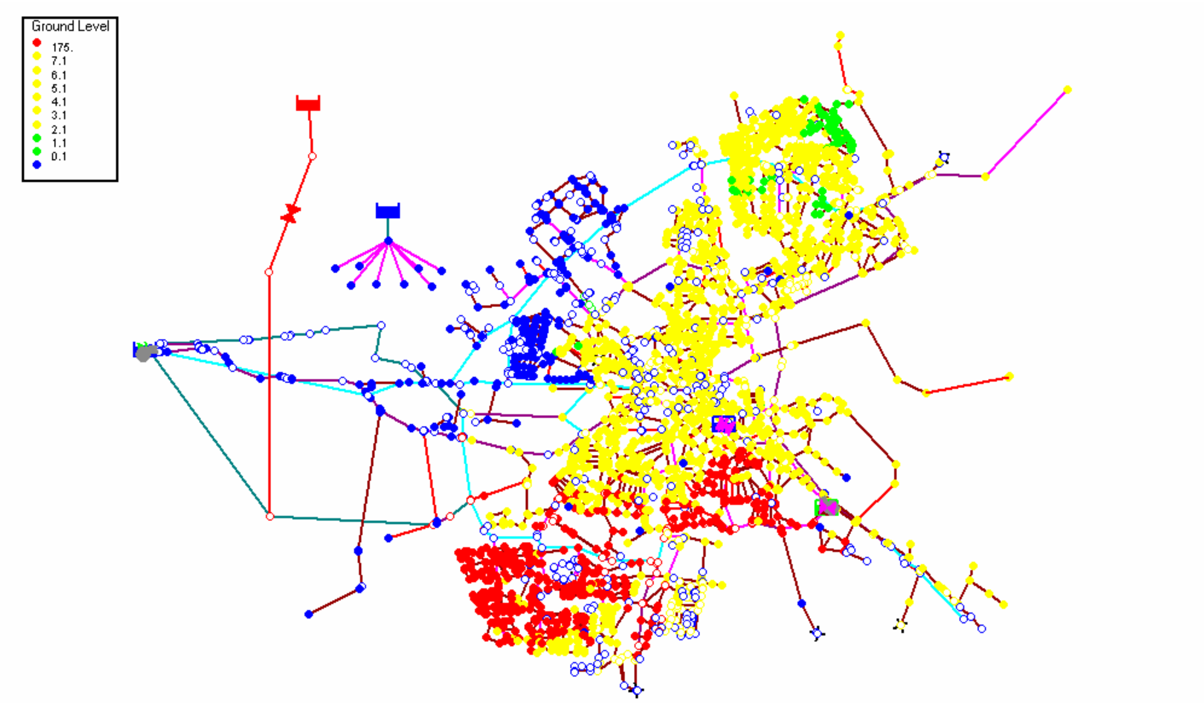


Figure 2.6: Calculated maximum concentrations when introducing a contaminant in a large supply main, reporting interval 30 minutes. The legend heading ground level should be replaced by concentration.

In figure 2.7, the maximum concentrations reached upon introducing the contaminant in the southern region of the distribution area, in a distribution pipe, i.e. at private residence level, are depicted. The contaminant is spread through almost the entire city because the water introduced in this area is only partially consumed in this area and therefore also transported to other parts of the network.

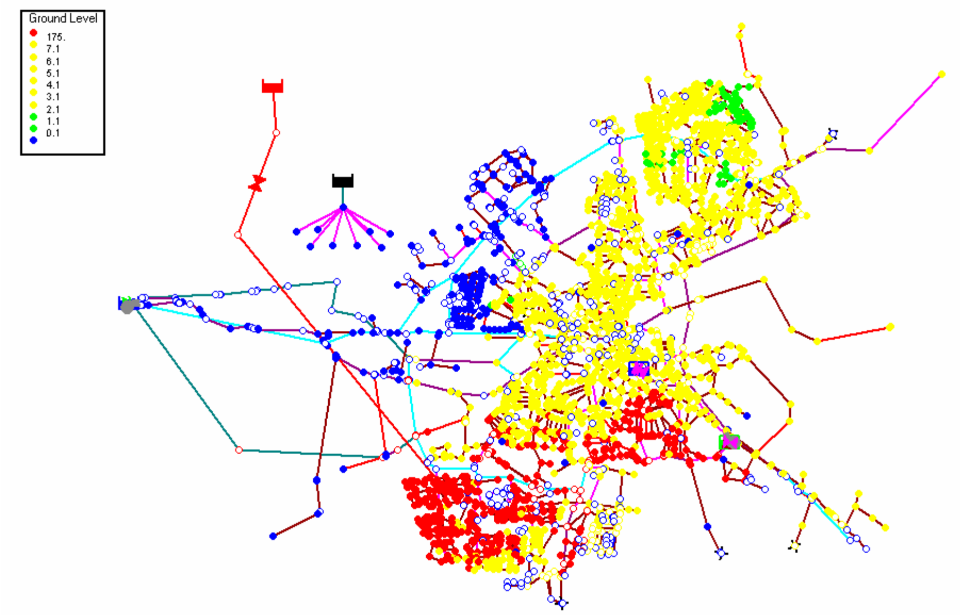


Figure 2.7: Calculated maximum concentrations when introducing a contaminant in a distribution pipe on the southern edge of the distribution area, reporting interval 30 minutes. The legend heading ground level should be replaced by concentration.

In figure 2.8 the calculated maximum concentrations for introduction of contaminant 'X' in a distribution pipe in the northern edge of the distribution area are shown. In this example, the spread of the contamination is limited to the area surrounding the point of introduction and the area of the network that is fed with this water.

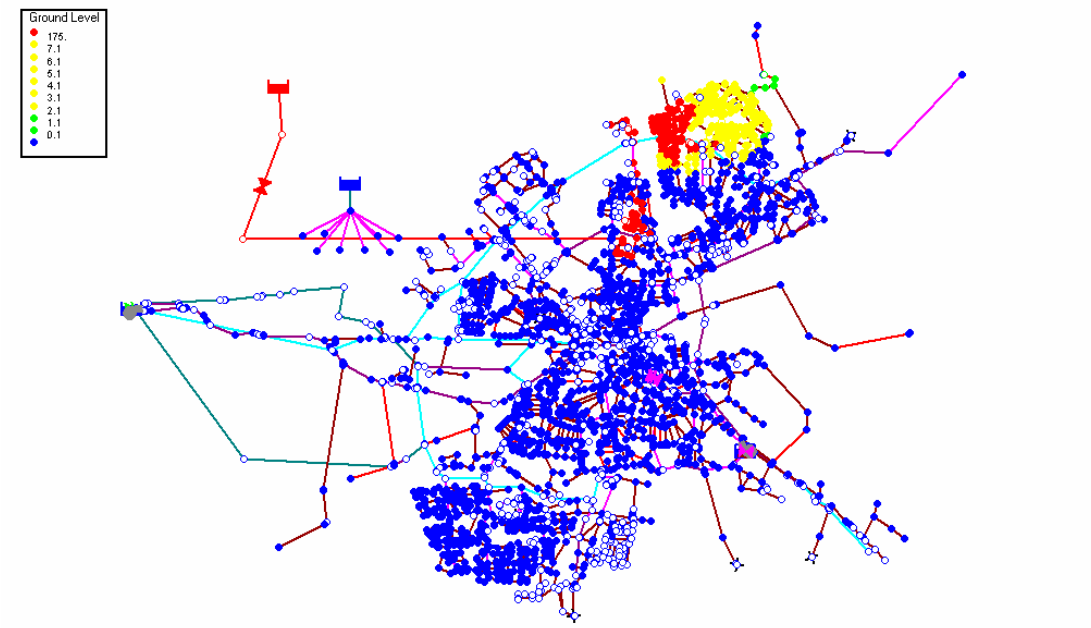


Figure 2.8: Calculated maximum concentrations when introducing a contaminant in a distribution pipe on the northern edge of the distribution area, reporting interval 30 minutes. The legend heading ground level should be replaced by concentration.

In figure 2.9, the maximum concentrations obtained upon introduction of the contaminant in the water tower are presented. Due to the large volume of the reservoir strong dilution of the contamination occurs, resulting in a maximum observed concentration below 30 mg/L

(C/C_0 = 6 10^{-4}) . Furthermore, this scenario shows that the influence remains limited to the eastern part of the distribution area. It must be noted that the spread of a contaminant originating from a reservoir is strongly dependent on the fashion in which the entire network is operated by the supply company.

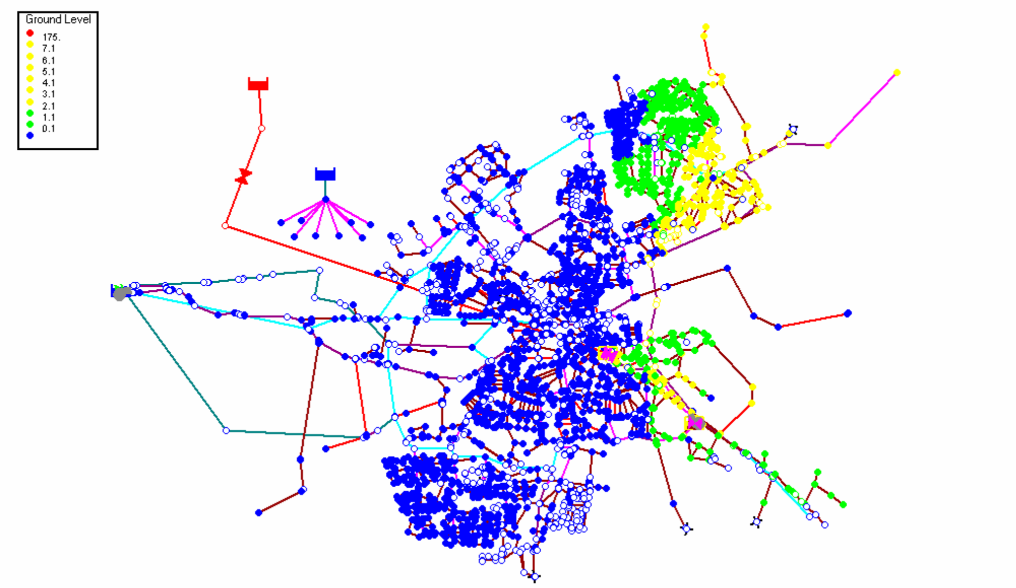


Figure 2.9: Calculated maximum concentrations when introducing a contaminant in the water tower, reporting interval 30 minutes. The legend heading ground level should be replaced by concentration.

In figure 2.10, the calculated maximum concentration achieved after introduction of the contaminant 'X' in the lower reservoir are shown. The area affected in this scenario is almost identical to the scenario where introduction in the water tower was simulated.

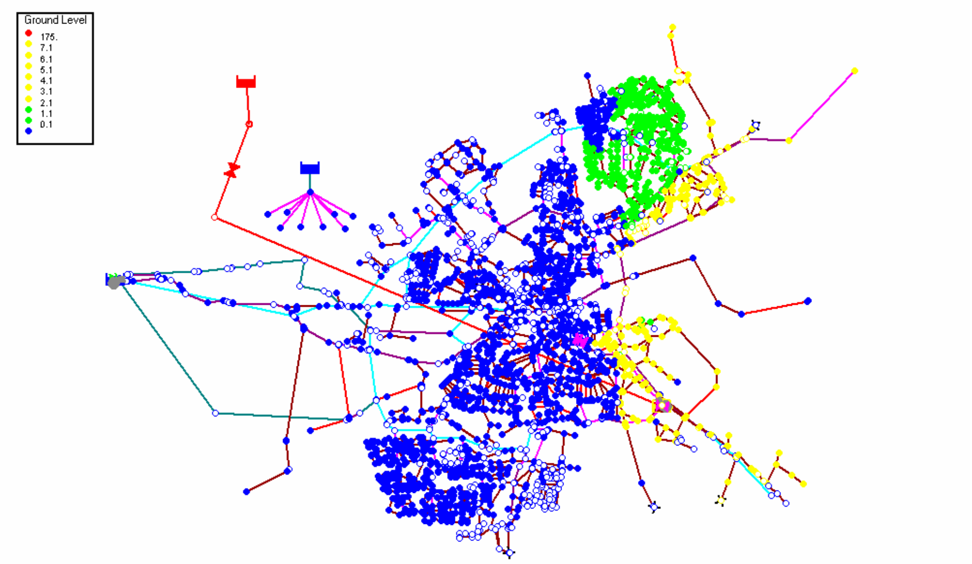


Figure 2.10: Calculated maximum concentrations when introducing a contaminant in the lower reservoir, reporting interval 30 minutes. The legend heading ground level should be replaced by concentration.

2.1.3 Assessment of the impact of the contaminant levels on the population of A

After calculating the concentration distributions in the network in the 6 scenarios, the impact of such a contamination on the public health was assessed. This was done on the basis of a number of presumptions, and must be considered as a very crude exercise. This estimation will clearly illustrate the impact of a relatively minor contamination event when a highly toxic or infectious agent is used.

2.1.3.1 Introduction of a toxic compound

Boundary conditions for the model study

To calculate the impact of the introduction of a toxic compound in the distribution network, a number of parameters has to be defined. For these scenario evaluations it was assumed that an average person has a bodyweight of 70 kg and drinks 2L of water every day. The total water consumption per capita is much larger, and some exposure will occur through contact with contaminated water during bathing or taking a shower. Only the oral route of exposure is used for the calculation of the impact of a chemical contamination, as for most toxic compounds this will be the major route of exposure.

The following boundary conditions were used:

- the average concentration at a node during the first 24 hours after introduction of the contaminant is used to calculate exposure;
- 100 kg of the contamination are introduced while dissolved in 2000 L.
- The following equation is used to calculate the exposure per individual at each node:

$$(\Sigma(conc)_t / N_t)*2L \qquad (2a)$$

where $(conc)_t$ = concentration in mg/L at time t, N_t = the number of reporting intervals in the 24 hours after introduction of the contaminant and 2L is the volume of water consumed.

After calculating the exposure at each node, the number of potential victims is calculated. A person is considered a potential victim when for the node at which his or her home is located the outcome of equation X equals or surpasses the LD_{50} value. The number of potential victims is then calculated by adding up the number of inhabitants at all nodes where the LD_{50} threshold is reached according to equation 2a. For the compounds Sarin ($LD_{50,\ oral}$ = 0.071 mg/kg bw) and mevinfos ($LD_{50,\ oral}$ = 2.2 mg/kg bw) the number of potential victims was assessed (table 2.1).

Care must be taken with the interpretation of the values listed in table 2.1. The numbers of potential victims are only a general indication for the exposure of the inhabitants of the town to an introduced contaminant. No definite conclusion can be drawn on the basis of these calculations. The reservations will be discussed in section 2.1.3.3.

Table 2.1. Potential victims upon introduction of Sarin or Mevinfos at the town A (percentage of total number of inhabitants in brackets).

Scenario (point of introduction)	Number of potential victims: Sarin	Mevinfos
1 (pumping station)	65,000 (92 %)	0 (0 %)
2 (large supply main)	28,000 (39 %)	20 (0.03 %)
3 (private home I)	37,000 (52 %)	1000 (1 %)
4 (private home II)	9000 (13 %)	1000 (1 %)
5 (reservoir)	0 (0 %)	0 (0 %)
6 (reservoir)	3000 (4 %)	0 (0 %)

2.1.3.2 Introduction of a pathogen

Boundary conditions for model study

To be able to estimate the impact of the introduction of a pathogen in the distribution network, a number of parameters have to be redefined. Again, an average human bodyweight of 70 kg was used. However, as micro organisms can be killed in boiling water, only the volume of non-boiled water consumed was used for these calculations. This volume was set at 0,5 L per person, per day. This is above the average consumed in the Netherlands, but represents the intake during a vulnerable point in time, e.g. during summertime. Furthermore, infection through inhalation, can be a highly important route of exposure for pathogens and was therefore incorporated in the calculations. Studies have shown that the average person uses 40 L of water for showering daily and that the inhalation of aerosols is a significant route of exposure to pathogens in water (Paustenbach, 2003; Xu, 2004); for every litre of water used approximately 1 - 10 µL of aerosol is inhaled. Using the highest estimate, this corresponds with a total ingestion of 400 µL of water.

For this model study, the effect of contamination of the water supply with two different micro-organisms (table 2.2) was estimated. Furthermore, for each organism, two different scenarios were assessed: addition of 2000 L of a medium containing the organism in a concentration of $1 \cdot 10^{12}$ particles/L and addition of this volume of medium containing the organism in a concentration of $1 \cdot 10^{8}$ particles/L.

Table 2.2: Properties of micro-organisms used in the simulation in town A.

Organisms	**Risk of infection per particle (oral)**	**Mortality amongst infected individuals (oral)**	**Risk of infection per particle (inhalation)**	**Mortality amongst infected individuals (inhalation)**
Francisella tularensis	$7.0 \cdot 10^{-9}$	35 %	0.01 – 0.07	30 – 60 %
Salmonella typhi	$7.0 \cdot 10^{-6}$	10 – 25 %	not applicable	not applicable

Calculation of exposure and risk of infection

The impact of contamination of the drinking water supply with pathogenic organisms is less straightforward to assess than for the introduction of a toxic compound. This is caused by the various risk factors that contribute to the overall effect of the pathogen: risk of exposure, risk of infection, risk of falling ill/dying from the infection. Using the 24 hour average concentrations per node and the number of inhabitants per node an assessment was made on the numbers of infected people in the simulated supply network. This was done using the equations introduced below.

When assuming that the pathogenic organism is distributed randomly in the water consumed, with D the average number of particles consumed, the chance that a consumer is exposed to one or multiple organisms (P_{exp}) is defined as:

$$P_{exp} = 1 - e^{-D} \qquad (2b)$$

with

$$D = C_{bact} \cdot V \qquad (2c)$$

where C_{bact} is the average concentration of bacteria and V is the consumed volume of water.

At high doses, P_{exp} will be close to 1, meaning exposure will always occur. When an organism can cause infection through both oral exposure and inhalation, the exposure via both these routes must be taken into account.

Assuming the relation between the dose to which a population is exposed and the number of infected individuals is best described using an exponential dose-response model, the risk of infection due to the exposure to a dosis D can be defined as:

$$P_{\mathrm{inf}} = 1 - e^{-r \cdot D} \qquad (2d)$$

where r is the infection risk upon exposure to a single organism.

If $r \cdot D << 1$, then:

$$P_{\mathrm{inf}} \approx r \cdot D \qquad (2e)$$

From this follows that the number of infected persons per node is:

$$P_{\mathrm{inf}} \cdot I_x \qquad (2f)$$

where I = number of inhabitants at a single node. The total number of infected persons then equals the sum of the number of infected persons over all nodes:

$$\Sigma(P_{\mathrm{inf}} \cdot I_x) \qquad (2g)$$

Using these equations an assessment was made of the number of infected persons in the 6 scenarios described in 2.1.1 (tables 2.3 and 2.4). As with the calculations on the contamination with a toxic compound, the estimates in tables 2.3 and 2.4 must be considered to be an indication for the order of magnitude only.

Table 2.3: Infection and mortality estimates upon introduction of *Francisella tularensis* in the supply network of A (percentage of total number of inhabitants in brackets).

Scenario	Concentration of contamination			
	10^8		10^{12}	
	Infected persons	Lethal casualties	Infected persons	Lethal casualties
1 (pumping station)	20,000 (28 %)	12,000 (17 %)	71,000 (100 %)	43,000 (61 %)
2 (large supply main)	13,000 (18 %)	8000 (11 %)	60,000 (85 %)	36,000 (51 %)
3 (private home I)	13,000 (18 %)	8000 (11 %)	60,000 (85 %)	36,000 (51 %)
4 (private home II)	4000 (6 %)	2000 (3 %)	10,000 (14 %)	6000 (9 %)
5 (reservoir)	1000 (1 %)	700 (1 %)	16,000 (23 %)	10,000 (14 %)
6 (reservoir)	300 (0.4 %)	200 (0.3 %)	4000 (6 %)	2000 (3 %)

Table 2.4: Infection and mortality estimates upon introduction of *Salmonella typhi* in the supply network of A (percentage of total number of inhabitants in brackets).

Scenario	Concentration of contamination			
	10^8		10^{12}	
	Infected persons	Lethal casualties	Infected persons	Lethal casualties
1 (pumping station)	3000 (4 %)	700 (0.1 %)	71,000 (100 %)	18,000 (25 %)
2 (large supply main)	2000 (3 %)	600 (0.9 %)	59,000 (83 %)	15,000 (21 %)
3 (private home I)	2000 (3 %)	600 (0.9 %)	59,000 (83 %)	15,000 (21 %)
4 (private home II)	1000 (1 %)	400 (0.6 %)	10,000 (14 %)	3000 (4 %)
5 (reservoir)	200 (0.3%)	50 (0.07 %)	14,000 (20 %)	4000 (6 %)
6 (reservoir)	4 (0.006 %)	1 (0.001 %)	3000 (4 %)	700 (0.1 %)

2.1.3.3 Discussion

The calculations performed using the ALEID software allow for the estimation of the spread of a contamination throughout a distribution network. Using both the peak concentrations and the distribution of the contaminant over the nodes in the network, it was possible to estimate the impact of introducing a known concentration in the supply system of A. Calculations for other supply systems could be performed, but for the purpose of demonstrating the effects that can be achieved by dosing a contaminant this single example provides sufficient information. An aspect that would change the impact of the contaminant would be the use of a disinfectant residual in the water distributed, as is common in the United States. This is not incorporated in the model, and the results obtained can not be extrapolated to such a situation. The most likely result would be a smaller impact of contamination with pathogens, and a reduction in the lifetime of certain chemicals. Therefore, the calculations performed estimate the impact on a Dutch drinking water supply system, and could be regarded as a worst case scenario for a US supply system.

The calculations clearly demonstrate the ease with which a huge impact can be achieved. Even when a contaminant is introduced at a private home level, which could be done with a minimal chance of discovery, hundreds or even thousands of consumers will be exposed to the contaminant. This is clearly demonstrated by the numbers of potential victims presented in the previous section. However, as stated in 2.1.3.2, due to many uncertainties and imperfections in the method for estimating the number of victims, as well as the unpredictability of the actions of a terrorist, these numbers must be treated as in indication for the order of magnitude only of the impact of an intentional contamination.

The most important limitations are:

- The use of a 24 hour average has an unknown influence on the result of the calculations. A contaminant will be present at most nodes for a relatively short time, and can reach a concentration level well above this average concentration. Figure 2.4 shows the concentration of the contaminant at two different nodes; illustrating the difficulty of predicting potential victims based on daily average concentrations;
- Daily patterns of consumption will determine the effect of concentration peaks. Only when high consumption coincides with a concentration peak will high exposure occur. For the pathogens even more detailed information is required, such as when do people consume non-boiled water. Such data were unavailable at the time these calculations were performed;
- using LD_{50} as a threshold value for toxic compounds is undesirable (50% mortality), but reliable data on no effect levels (NOEL) for humans are often unavailable. The use of LD_{50} values will result in a crude prediction of the number of mortalities that is to be expected, and not in a prediction of the number of people that fall ill due to the toxic compound. This can be expected to be significantly higher than the values presented in table 2.1;
- uncertainty about the model used for exposure to pathogens.

Keeping these reservations in mind, the calculations performed using the ALEID output allow for drawing a number of conclusions.

- The number of people that will be exposed depends on the point of entry. The number increases upon introduction at a point that is closer to the pumping station, i.e. the source for the entire network. However, even when introduced from a private residence in a relatively isolated area of the network, the number of people exposed to the contaminant will be high, i.e. hundreds or thousands.
- Using a limited amount of compound/pathogen, e.g. several kg of a toxic compound, peak concentrations well above LD_{50} levels can be achieved when introduced at the private residence level.
- When the contaminant reaches a reservoir, its presence in the network will be increased to several days, albeit at very low concentrations.
- Introduction of a contaminant at one of the reservoirs is the least efficient manner, as the dilution in the large volume of the reservoir reduces the maximum concentration achieved.
- When introducing pathogens, the low level concentrations present after the contaminants reach the reservoir can still result in a significant risk of infection, especially when present over the period of several days.

2.1.3.4 Source material

Paustenbach, D.J.; Finley, B.L.; Mowat, F.S.; Kerger, B.D. *J. Toxicol. Environ. Health A* **2003**, *66*, 1295 – 1339.
Xu, X.; Weisel, C.P. *Environ. Sci. Technol.* **2004**, *38*, 1799 – 1806

2.2 Evaluation of the boundary conditions of an effective application of EWS

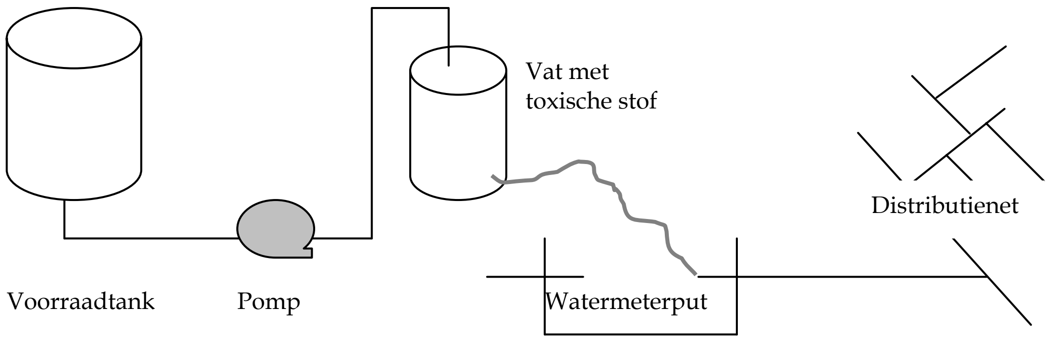
Calculations simulating the detection of a contaminant by an EWS were made for a Dutch town (town B), the network of this town being considered to be fairly representative of an urban drinking water network. Town B is a medium-sized municipality with around 60,000 residents and approximately 24,000 connections. The network is fed from the centre by a single pumping station and it contains one de-central reservoir.

2.2.1 Approach to modelling

2.2.1.1 Definition of a terrorist attack

A toxic substance injected into the water mains system could spread almost unnoticed through the distribution network and would only be detected when the first reports of effects on people occurred. A large part of the water mains system would already have been contaminated by then.

For this study, is was assumed that the most harmful impact would result from an attack that involved pumping a severely toxic contaminant into the distribution network from a home as it could take place practically unnoticed. The contaminant could be fed into the supply system according to the setup depicted in figure 2.11. Furthermore, this type of attack is the most difficult to detect in time to prevent exposure of the public, as the time between injection of the contaminant and exposure is the shortest (see chapter 2.1).



Distributienet = Distribution network
Voorraadtank = Supply tank
Pomp = Pump
Vat met toxische stof = Drum containing toxic substance
Watermeterput = Water meter chamber

Figure 2.11. Contamination of the supply network with a toxic compound from a private residence.

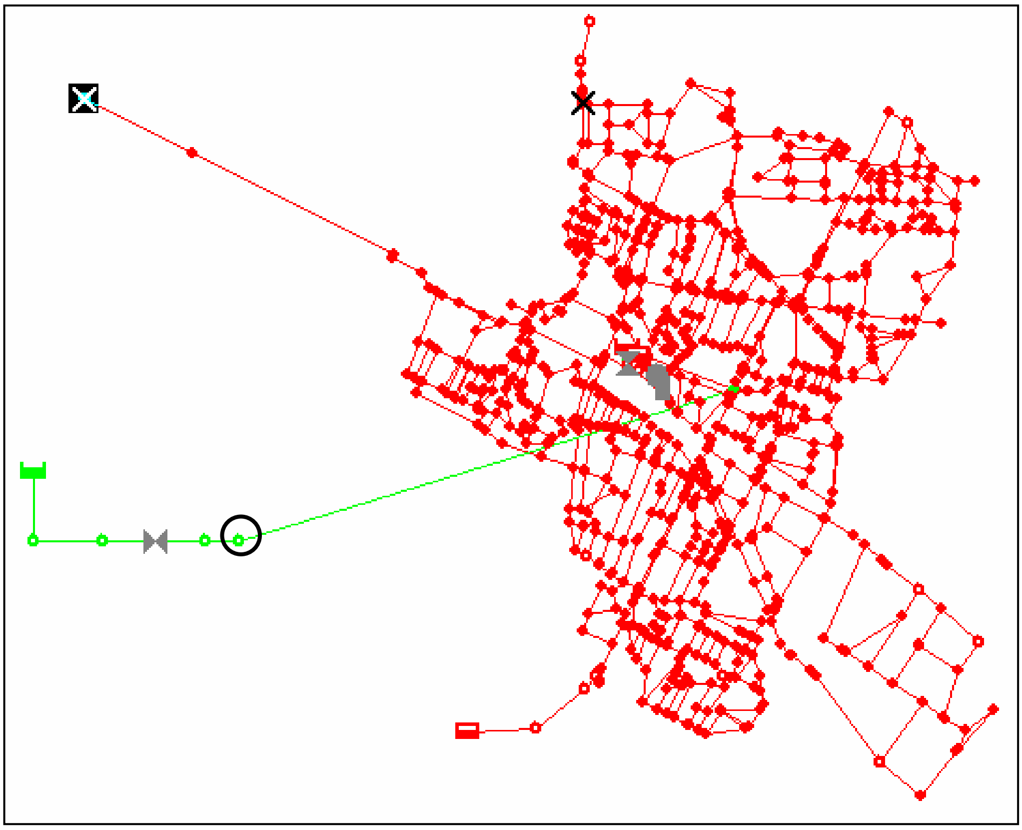


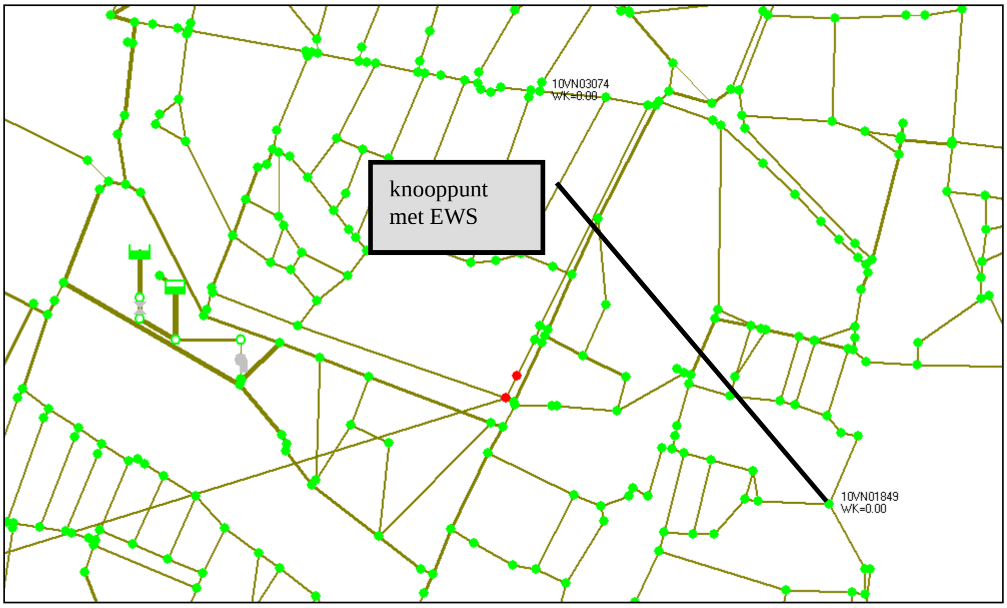
Figure 2.12. Overview of town B's water mains system and modelling of the injection of a toxic substance (see green node. The contamination is injected in the encircled node).

2.2.1.2 Illustration of how a toxic substance spreads

The starting point for simulating the contamination illustrated in figure 2.12 was that a 200 litre drum full of a toxic substance was injected into the network within one hour at the location of a consumption node. Using a pump with a constant outflow pressure of 70 metres water column (98 psi), a constant volume flow of 1 m^3/h would be introduced into the distribution network.

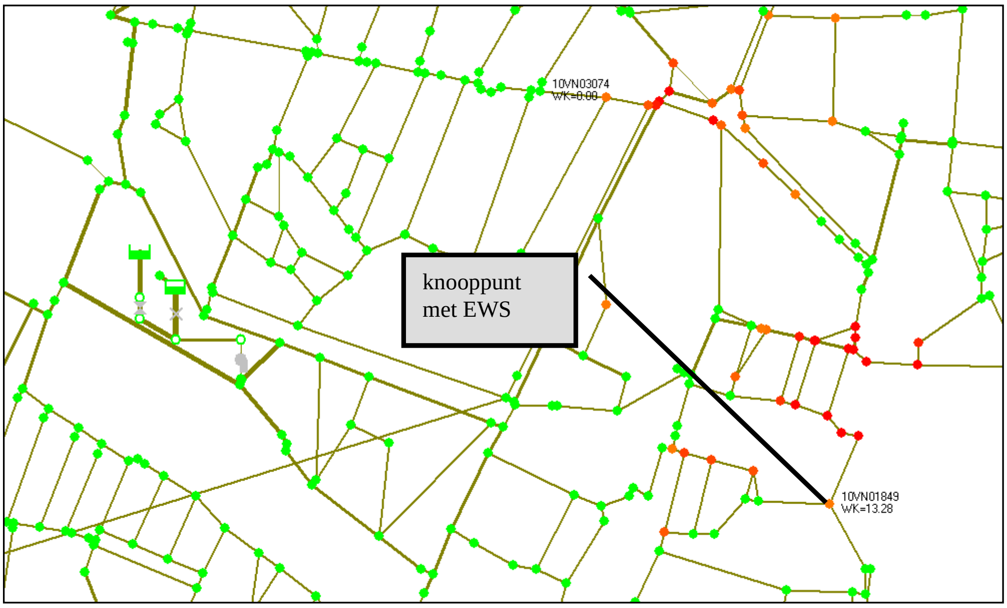
In figure 2.12, the green nodes and pipes represent the injection device for the toxic substance. A contamination of 200,000 mg/L is injected at a consumption node, after which the spread of the contamination is simulated for one hour by means of a contamination pattern.

Figure 2.13 and figure 2.14 show how the toxic substance moves through the water mains system under the influence of the water flow. Figure 2.13 shows the contamination at 1:30, half an hour after the start. The contamination is detected at 7:30 by an EWS in node number 10VN01849 (figure 2.14), after which the pumps will be stopped.



knooppunt met EWS = node equipped with EWS

Figure 2.13. Situation at 1:30: the contamination (red nodes) spreads through the network, 30 minutes after the contamination was injected.



knooppunt met EWS = node equipped with EWS

Figure 2.14. Situation at 7:30: the red points indicate where the contamination is located. This is the time at which the EWS detects the contamination.

2.2.1.3 Description of the modelling

The water mains system programme ALEID2002 was used for modelling, and the water quality module was used for simulating impacts of contamination.

The following starting points were adopted for the calculations:
1. The calculation was made for a day with average water consumption.
2. Consumption in the model over a period of 24 hours was determined using hour factors. This method can be used for larger groups of consumers. For a detailed water mains system model such as the one used in these calculations, the dynamics of water consumption at street level will be greater than that determined using hour factors. However, no programme for water mains system calculations is available that can calculate using these flow dynamics on a small scale. For the time being, therefore, it is assumed that consumption determined using the hour factors provides a sufficiently accurate description of the actual situation.
3. The hydraulic and water quality calculations were made at intervals of 10 minutes.
4. The contamination in the distribution network behaved as a conservative substance (e.g. no decomposition, adsorption, etc.) that moved with a uniform horizontal flow profile, with an even rate of distribution over the height of the pipe.
5. It is assumed that an early warning system (EWS) is situated at a consumption node and that the contamination is recognized immediately upon reaching the EWS, regardless of the measured concentration.
6. Once identified by the EWS, the contamination is deemed to pose such a health hazard that validation of the measurement is not required. A signal will be sent to the pumping station immediately to switch off the high-pressure pumps, so that the drinking water supply will be cut off immediately.
7. The impact of the contamination has been analysed for an attack that occurred in the early night and during the morning consumption peak.

The distribution of the contamination will be more widespread than calculated. This is because, on the one hand, the flow dynamics on a small scale (starting point 2) are actually larger than the calculated figure. On the other hand, the water does not move at an even rate of distribution (starting point 4) but will move in the middle of the pipe's height at a faster than average rate ($V_{max} \approx 1.2 - 1.3 * V_{ave}$). The effect of the uniform horizontal flow profile (movement of a given volume of contaminated water) will decline over time as mixing occurs before and after the contaminated volume of water.

Calculations are also performed to determine the following parameters at the moment that the EWS detects the contamination:
- the percentage of nodes where contaminated water has been consumed in relation to the total number of nodes where consumption is permitted;
- the amount of use made of the nodes where the contaminated water has been consumed in relation to total daily consumption.

These calculations determine the impact of the terrorist attack using a toxic substance for contamination that takes place between 1 a.m. and 2 a.m. and between 8 a.m. and 9 a.m. These situations are assumed to be the extremes;

- water consumption is at its lowest point during the early part of the night. Introduction early in the night means that flow dynamics are low at the time of the injection of the contaminant, and therefore the likelihood of detection is low.
- the contamination was injected between 8 a.m. and 9 a.m., which is the morning peak, with maximum dynamics. During this time of the day, distribution of contamination and the likelihood of detection are greatest.

2.2.1.4 Distribution of early warning systems in the mains system

Additional water mains system calculations were performed to investigate the effect of the number of EWS in the distribution network on the impact of the contamination. Calculations were proposed for 1 EWS per 25,000 connections, 1 EWS per 2500 connections and 1 EWS per 250 connections. For town B, with around 24,000 connections, this would amount to 1 EWS, 10 EWS and 96 EWS respectively.
As seen in Figure 2.12, town B is fed from the centre. In a situation of this kind, the choice in practice would be for 1 EWS on the northern side and 1 EWS on the southern side. For this practical reason, distribution levels of 2, 10 and 96 EWS were adopted. See the figures below for the distribution of the EWS locations.

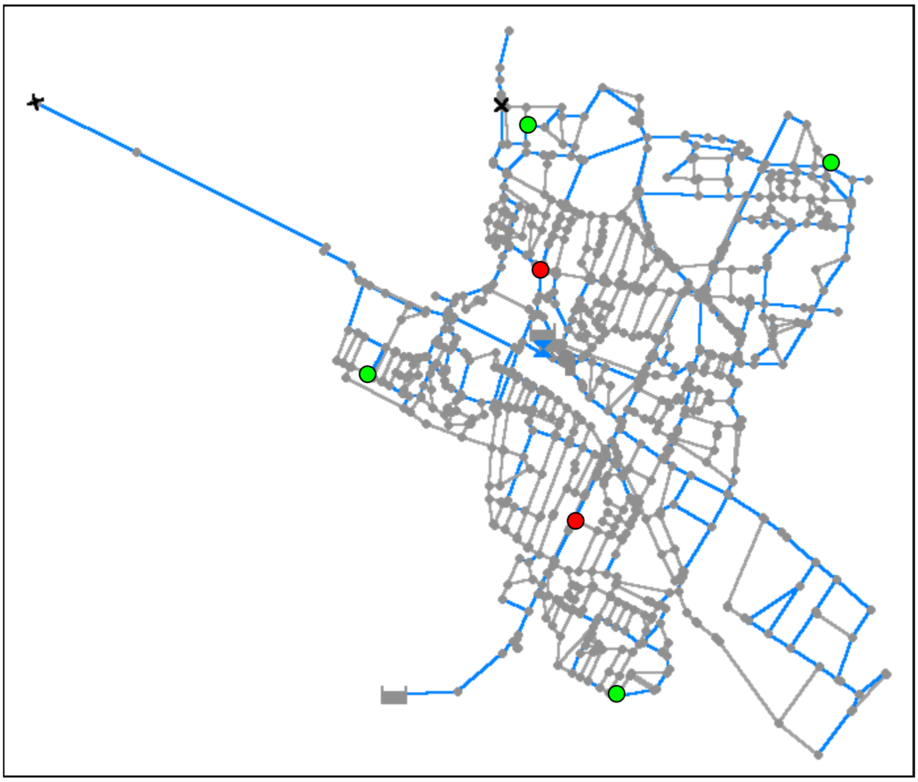


Figure 2.15. Overview of locations for 2 EWS. Four peripheral locations are also shown (in green); for details see section 2.2.1.1.

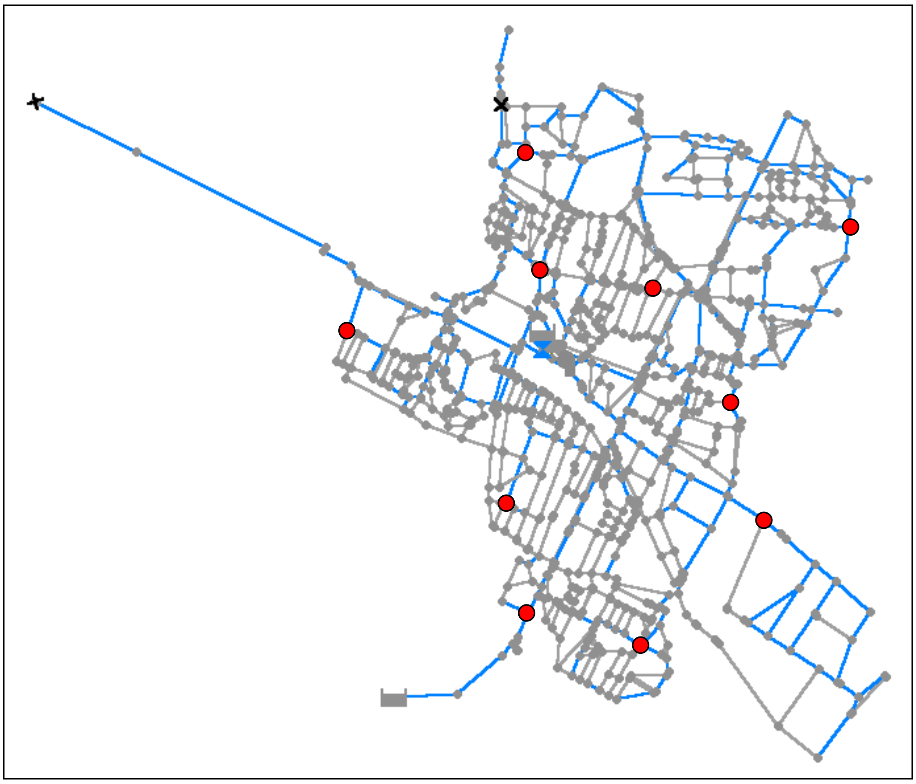


Figure 2.16. Overview of locations for 10 EWS

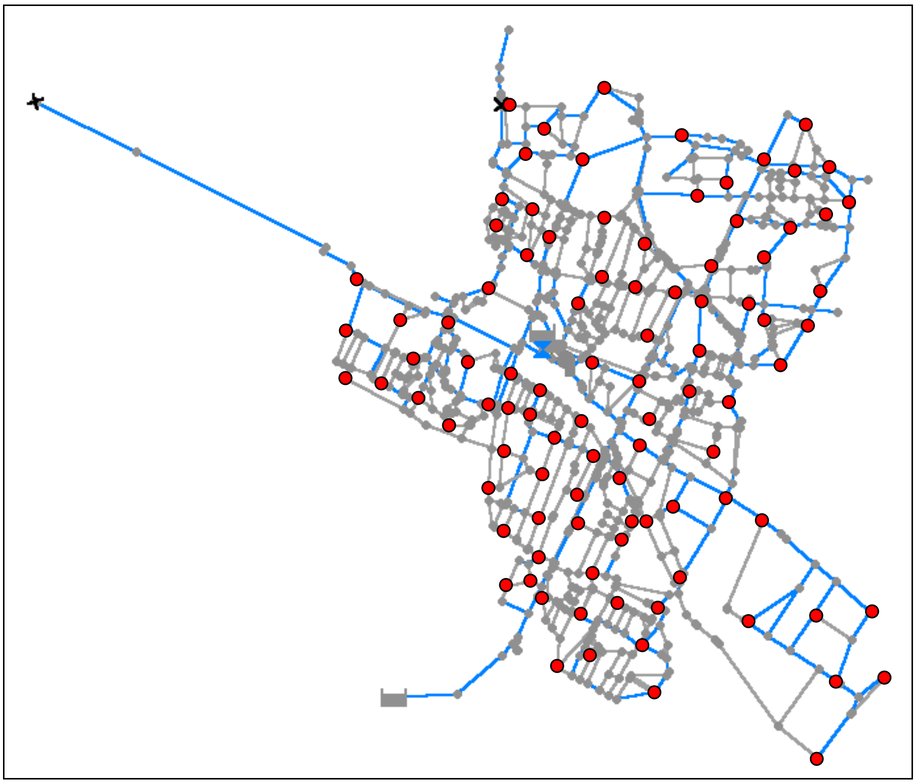
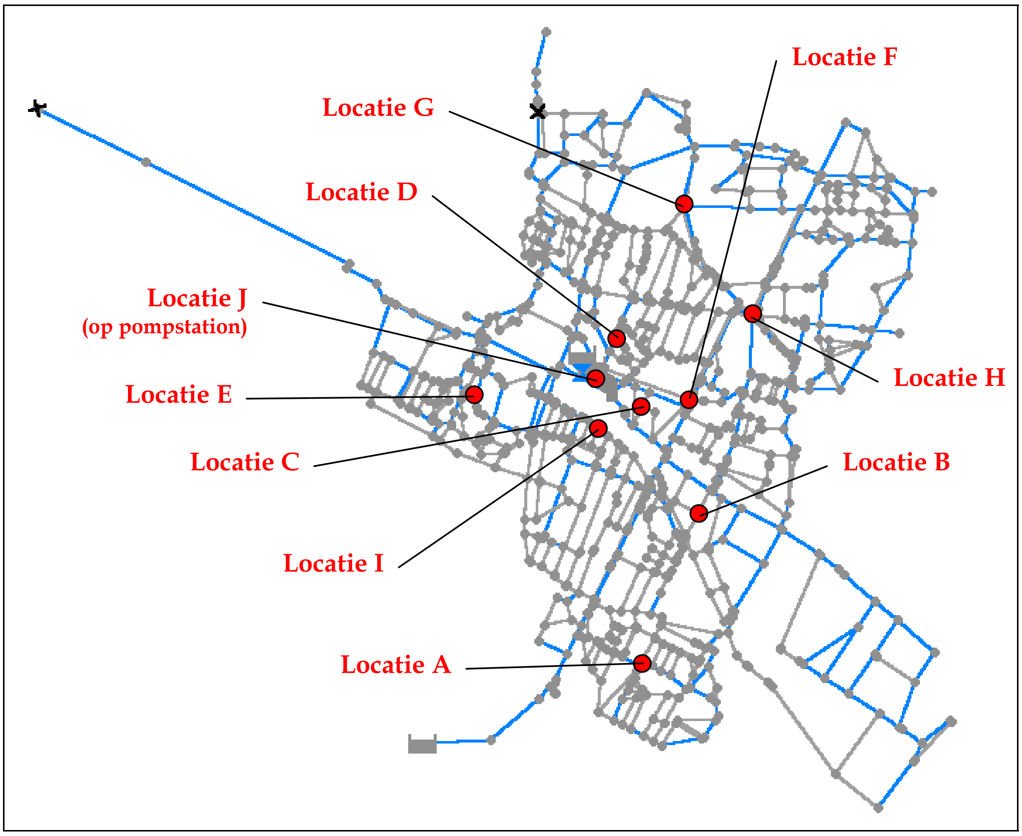


Figure 2.17. Overview of locations for 96 EWS

2.2.1.5 Distribution of injection points for a toxic substance

The impact of injecting a toxic substance through a house connection was analysed by simulating contamination in B's water mains system model at 10 different locations. The locations of contamination injection are shown in Figure 2.18. The choice of locations was determined by the flow directions, whereby the aim was to arrange for the contamination to be injected where it would cause the greatest damage. A number of locations are away from the centre, where the likelihood of detection by an EWS is expected to be lower. Other locations are closer to the centre, which means detection is considered more likely but the contamination will extend over a wider area.



Lokatie = Location
(op pompstation) = (at pumping station)

Figure 2.18. Assumed contamination locations

2.2.2 Town B calculation results

2.2.2.1 Introduction of contamination between 1 a.m. and 2 a.m.

In the first set of calculations, the contaminant was injected between 1 a.m. and 2 a.m. Water consumption is at its lowest point during the early part of the night. This means that flow dynamics are low at the time of the contaminant's injection, and the likelihood of detection is also low. The rate of distribution remains low for a few hours, until the morning peak, when distribution of contamination and the likelihood of detection are greatest.

The results of the calculations are summarized in Table 2.5. Ten calculations were made for 2, 10 and 96 EWS respectively. Five additional calculations were also made in which four EWS were placed on the periphery of the water mains system (figure 2.15). The column in the table entitled “detection” shows the hours at which first detection by an EWS occurs. The column entitled “% nodes” shows the percentage of the total number of nodes where contaminated water will have been consumed up to the time of detection. The column entitled “% consumption” shows the amount of use made of the nodes where the contaminated water has been consumed in relation to total daily consumption.

With 2 EWS installed, it was calculated that in the water mains system of town B an average of 14% of the nodes and 14% of daily consumption may be contaminated. With 10 EWS the figure is 8% of the nodes and 7% of consumption; with 96 EWS the figure is 1% of the nodes and 1% of consumption. With 4 EWS installed on the periphery of the water mains system, contamination affects an average of 23% of the nodes and 23% of consumption.

The calculations show a wide variation in results. Further analysis of individual calculations showed that it is possible for a plug of contaminated water to move through the network, with the contamination by-passing a node where an EWS is located. In other cases, contamination moved towards an EWS and came to a halt just before the EWS. In this case, contamination was only detected after 8 a.m. by another EWS (see appendix I). This indicates that proper analysis of water flows is necessary for determining precisely where an EWS should be located in a distribution network.

2.2.2.2 Contamination between 8 a.m. and 9 a.m.

In the next set of calculations the contamination was injected between 8 a.m. and 9 a.m., when maximum consumption occurs. This is the morning peak, with maximum dynamics, when distribution of contamination and the likelihood of detection are greatest.

The results of the 10 calculations are summarized in Table 2.6. The set-up of this table is identical to that of table 2.5. With 2 EWS installed an average of 13% of the nodes and 13% of daily consumption may be contaminated. With 10 EWS the figure is 9% of the nodes and 8% of consumption; with 96 EWS the figure is 1% of the nodes and 1% of consumption. With 4 EWS installed on the periphery of the water mains system, contamination affects an average of 21% of the nodes and 20% of consumption. As with the calculations for contamination between 1 a.m. and 2 a.m., there is a wide variation in results.

Table 2.5. Overview of calculation results for contamination between 1 a.m. and 2 a.m.

	2 EWS			**10 EWS**			**96 EWS**			**4 EWS periphery**		
Injection Point	Time of Detection	% nodes	% consumption	Time of detection	% Nodes	% consumption	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption
A	no det	7.45%	7.22%	04:50	2.93%	1.65%	01:30	0.23%	0.06%			
B	no det	16.70%	17.46%	07:20	5.31%	5.75%	02:50	0.68%	0.80%			
C	09:00	21.10%	18.59%	08:40	18.06%	15.42%	05:40	0.68%	0.90%			
D	no det	26.86%	28.61%	05:40	5.99%	3.66%	01:40	0.56%	0.20%			
E	no det	16.82%	13.09%	11:40	3.72%	3.16%	06:30	1.80%	1.28%			
F	no det	21.56%	23.68%	07:30	7.56%	6.21%	05:00	2.14%	1.74%	no det	21.56%	23.68%
G	no det	6.89%	10.42%	no det	6.89%	10.42%	06:00	0.56%	1.68%	no det	6.89%	10.42%
H	no det	6.10%	7.70%	no det	6.10%	7.70%	04:20	1.01%	0.83%	no det	6.10%	7.70%
I	07:40	10.49%	9.85%	10:20	18.28%	13.77%	01:50	0.45%	0.32%	12:40	23.37%	19.47%
J	03:40	7.23%	5.65%	03:40	7.23%	5.65%	01:40	0.68%	0.56%	08:30	59.14%	55.12%
Average	**.**	**14.12%**	**14.23%**		**8.21%**	**7.34%**		**0.88%**	**0.84%**		**23.41%**	**23.28%**
st.dev	**.**	**7.5%**	**7.6%**		**5.5%**	**4.5%**		**0.6%**	**0.6%**		**22%**	**19%**

No det = no detection occurred

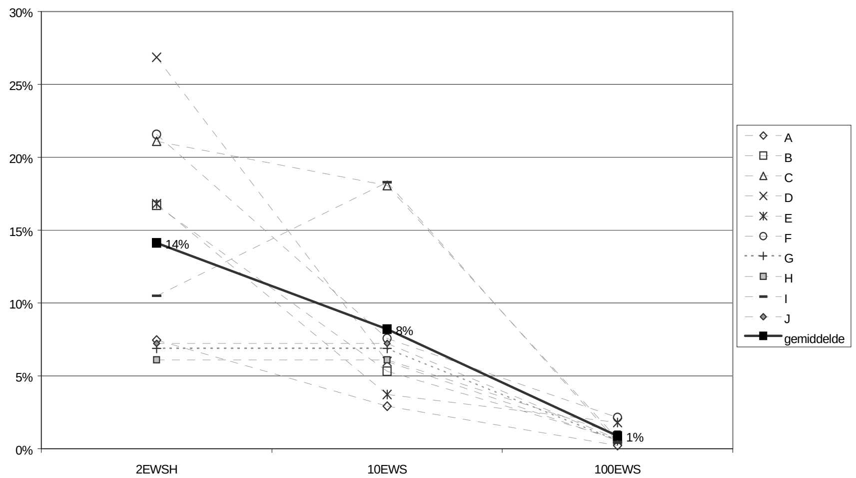


Figure 2.19. Contamination between 1 a.m. and 2 a.m., number of of contaminated nodes.

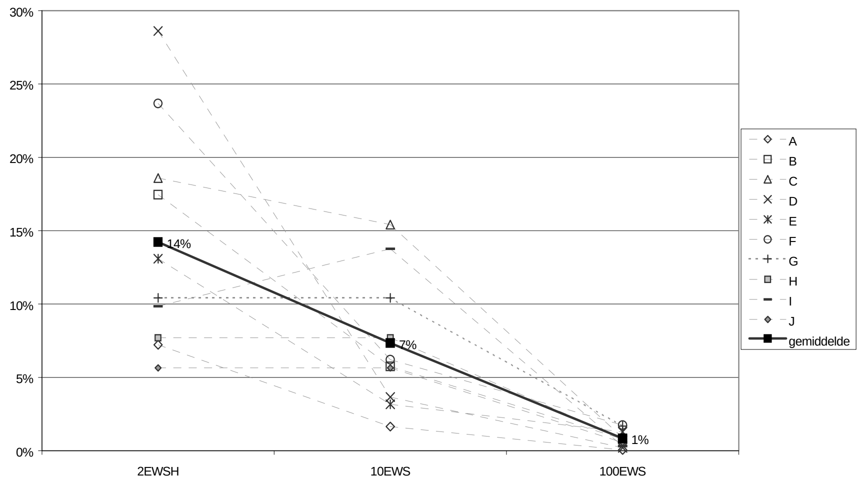


Figure 2.20. Contamination between 1 a.m. and 2 a.m., percentage contaminated consumption.

Table 2.6. Overview of calculation results for contamination between 8 a.m. and 9 a.m.

	2 EWS			10 EWS			96 EWS			4 EWS periphery		
Injection Point	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption
A	no det	4.97%	5.88%	09:20	2.37%	1.93%	08:50	1.47%	0.96%			
B	no det	11.06%	11.28%	14:00	6.66%	5.75%	08:20	0.45%	0.64%			
C	12:30	20.99%	18.10%	12:10	18.17%	15.64%	09:20	0.56%	0.56%			
D	no det	24.94%	26.35%	10:40	7.23%	5.83%	08:30	0.90%	0.34%			
E	no det	15.80%	11.89%	14:20	3.61%	3.44%	10:00	1.69%	1.19%			
F	no det	14.90%	15.40%	15:30	9.14%	9.28%	09:20	1.35%	1.24%			
G	no det	6.10%	9.83%	no det	6.10%	9.83%	09:10	0.45%	1.99%	no det	6.10%	9.83%
H	no det	6.10%	7.70%	no det	6.10%	7.70%	08:50	1.47%	1.12%	no det	6.10%	7.70%
I	no det	15.69%	12.04%	16:20	13.89%	8.58%	08:30	0.56%	0.45%	17:30	15.69%	12.04%
J	09:40	13.55%	12.21%	09:40	13.55%	12.21%	08:20	0.79%	0.65%	12:10	57.90%	51.64%
Average		**13.44%**	**13.07%**		**8.68%**	**8.02%**		**0.97%**	**0.91%**		**21.45%**	**20.30%**
st.dev.		**6.6%**	**5.8%**		**5.3%**	**4.1%**		**0.5%**	**0.5%**		**24.7%**	**21.0%**

No det = no detection occurred

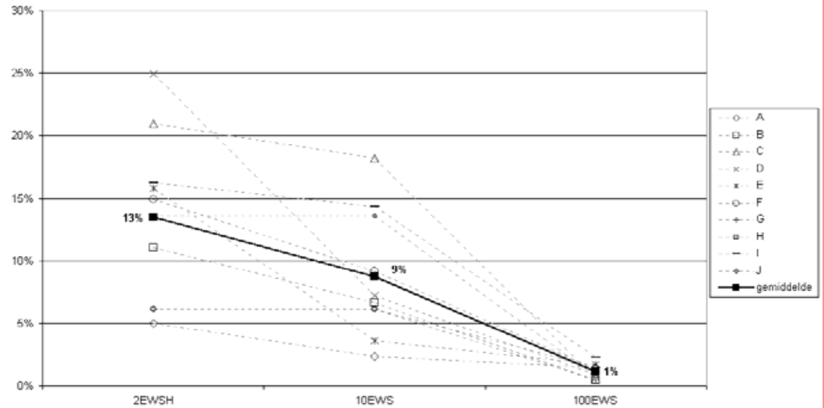


Figure 2.21. Contamination between 8 a.m. and 9 a.m., number of of contaminated nodes.

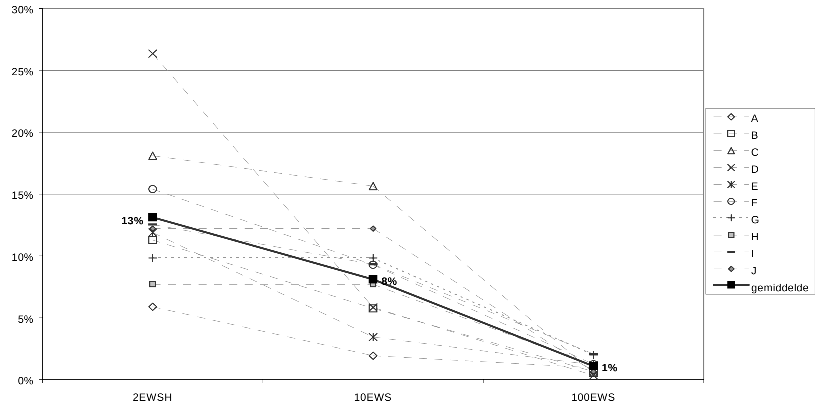


Figure 2.22. Contamination between 8 a.m. and 9 a.m., percentage contaminated consumption.

2.2.2.3 Comparison of the night-time and morning calculations

The calculations for the night and morning represent a period of minimum and maximum consumption respectively. A comparison of results shows that the impact of contamination is similar. This is valid for the number of contaminated nodes as well as the total volume of contaminated water consumed.
It is striking that there is a wide variation in results in both calculations, the results being strongly dependent on the place of the attack. This means that the network's safety from attack cannot be checked using just a few calculations and that before installing any EWS it is necessary to have a good insight into water flows. This requires modelling using a water mains system calculation programme that accurately represents the distribution network (1:1 model).

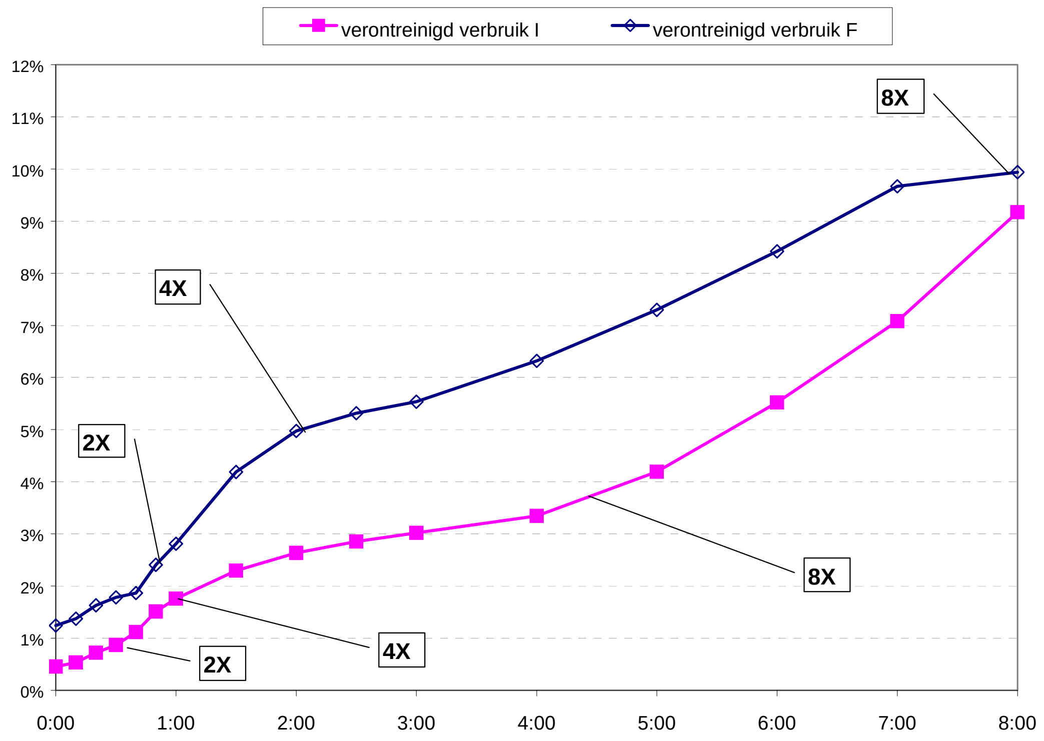
A few calculations were made in which some EWS were installed at the extremities of the network. As might be expected, this results in larger parts of the network being contaminated before detection occurs.

2.2.2.4 Effect of the response time of EWS

For two scenarios calculated and described previously it was examined what the effect of the response time of an EWS, i.e. the time between arrival of a contamination at a node equipped with an EWS and the moment the EWS has detected the substance and gives an alarm signal. The effect of the response time is shown in figure 1.23, using the scenario of contamination between 8 a.m. and 9 a.m. and 96 EWS, and for injection points F and I.

The percentage of contaminated water consumed in the case of injection at point F was 1.2%. for immediate detection. With a response time of 10 minutes, 1.4% will be consumed and with in case of a response time of 30 minutes 1.8% will be consumed. Furthermore, it was calculated that the percentage of contaminated water consumed will double for a response time of approximately 50 minutes and will quadruple for a response time of approximately 2 hours.

In the event of contamination at point I, the percentage of contaminated water consumed is 0.5% lower than in case of contamination at point F. However, the effect of the response time of the EWS more pronounced in the former scenario; with response time of 10 minutes, the percentage hardly increases, but for a response time of 30 minutes 0.9% of the contaminated water is consumed. This a doubling of the consumption of contaminated water in 30 minutes, and the model predicts a quadrupling of the original figure of 0.5% for a response time of approximately 1 hour.



verontreinigd verbruik = consumption of total amount of contaminated water

Figure 2.23. Effect of response time on increase in consumption of contaminated water.

2.2.3 Calculation of the effects of the location of the pumping station

2.2.3.1 General

This part examines the extent to which the location of the pumping station is a determining factor for the impact of injecting a toxic substance into the water mains system through a house connection. This was analysed by assuming that the input was not injected at the centre but at the periphery of the distribution area. It was assumed that the pumping station was located at the reservoir on the southern side (figure 2.12). The contamination locations referred to in the preceding chapter were also used for the calculations. Injection point J was not incorporated in this series of calculation, as this is situated at the pumping station and the results were expected to be similar to those obtained for the calculations for injection point C.

2.2.3.2 Contamination between 1 a.m. and 2 a.m.

In the first set of calculations, the contaminant was injected between 1 a.m. and 2 a.m. Calculations were made for 2, 10 and 96 EWS respectively. The results of the calculations are summarized in table 2.7. With 2 EWS installed an average of 11% of the nodes and 11% of daily consumption may be contaminated. With 10 EWS the figure is 5% of the nodes and 5% of consumption; with 96 EWS the figure is 1% of the nodes and 1% of consumption.

2.2.3.3 Contamination between 8 a.m. and 9 a.m.

In the next set of calculations the contamination was injected between 8 a.m. and 9 a.m. The results of the 9 calculations are summarized in table 1.8. With 2 EWS installed an average of 10% of the nodes and 10% of daily consumption may be contaminated. With 10 EWS the figure is 5% of the nodes and 5% of consumption; with 96 EWS the figure is 1% of the nodes and 1% of consumption (see figures 2.26 and 2.27).

2.2.3.4 Comparison of the night-time and morning calculations

The calculations for the night and morning represent a period of minimum consumption and maximum consumption respectively. A comparison of results shows that the impact of contamination is more or less the same. This applies to the number of contaminated nodes as well as the total volume of contaminated water consumed. As in section 2.2.2.2, there was a wide variation in results.

Table 2.7. Overview of calculation results for contamination between 1 a.m. and 2 a.m.

	2 EWS			10 EWS			96 EWS		
Injection Point	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption
A	09:40	34.14%	31.69%	02:40	2.86%	1.93%	02:10	1.65%	1.02%
B	08:50	22.47%	19.94%	06:50	9.47%	8.13%	02:40	1.32%	1.16%
C	10:20	5.29%	4.15%	10:20	5.29%	4.15%	08:20	0.44%	0.54%
D	no det	8.81%	9.96%	14:10	7.27%	6.86%	02:00	0.44%	0.12%
E	no det	4.63%	4.82%	09:50	3.08%	3.65%	07:00	1.10%	0.50%
F	no det	11.45%	12.82%	07:30	4.41%	4.65%	03:50	0.88%	0.79%
G	no det	1.10%	2.18%	no det	1.10%	2.18%	09:10	0.22%	1.31%
H	no det	4.96%	5.33%	no det	4.96%	5.33%	02:30	0.44%	0.37%
I	06:30	4.19%	4.01%	06:30	4.19%	4.01%	02:00	1.54%	0.91%
average		**10.78%**	**10.54%**		**4.74%**	**4.54%**		**0.89%**	**0.75%**
st.dev.		**10.8%**	**9.7%**		**2.5%**	**2.0%**		**0.5%**	**0.4%**

No det = no detection by an EWS

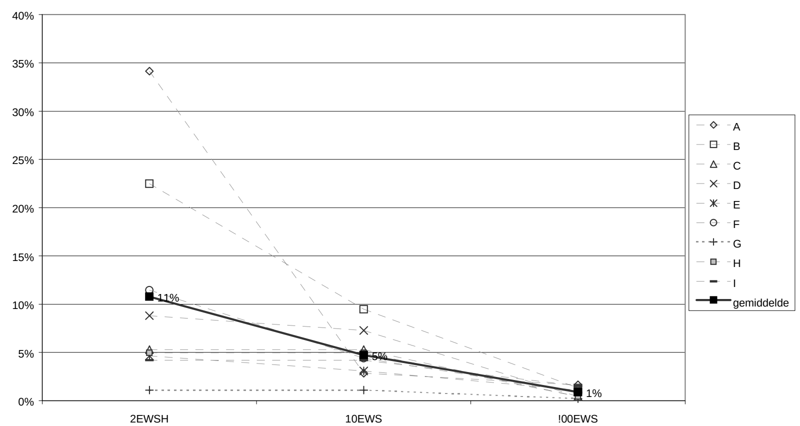


Figure 2.24. Contamination between 1 a.m. and 2 a.m., number of contaminated nodes.

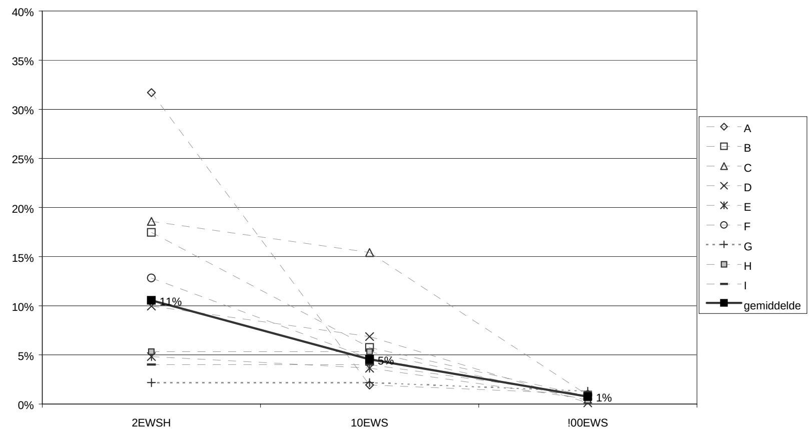


Figure 2.25. Contamination between 1 a.m. and 2 a.m., percentage of total consumption contaminated.

Table 2.8. Overview of calculation results for contamination between 8 a.m. and 9 a.m.

	2 EWS			10 EWS			96 EWS		
Injection point	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption	Time of detection	% nodes	% consumption
A	15:50	38.11%	38.39%	09:10	4.30%	3.02%	08:30	1.21%	0.64%
B	11:30	15.09%	12.81%	10:50	10.46%	9.61%	08:30	0.66%	0.56%
C	07:50	6.83%	6.20%	07:50	6.83%	6.20%	02:40	0.44%	0.54%
D	no det	8.70%	9.64%	17:10	7.38%	6.86%	08:30	0.66%	0.23%
E	no det	1.32%	1.10%	no det	1.32%	1.10%	16:10	0.88%	0.63%
F	no det	11.34%	12.50%	10:30	4.63%	3.98%	09:10	1.21%	1.12%
G	no det	1.76%	3.28%	no det	1.76%	3.28%	06:40	0.44%	2.12%
H	no det	4.96%	5.33%	no det	4.96%	5.33%	08:30	0.66%	0.57%
I	11:10	5.95%	4.78%	11:10	5.95%	4.78%	08:40	0.99%	0.37%
Average		**10.45%**	**10.45%**		**5.29%**	**4.91%**		**0.79%**	**0.75%**
st.dev.		**11.3%**	**11.2%**		**2.8%**	**2.5%**		**0.3%**	**0.6%**

No det = no detection by an EWS

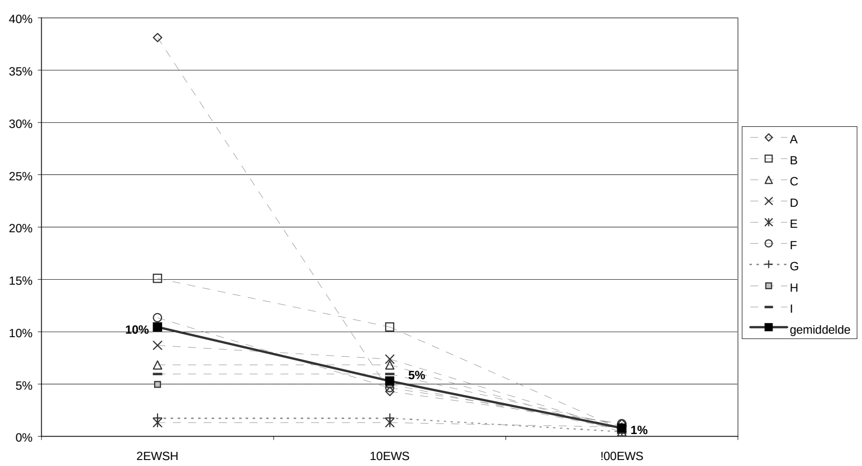


Figure 2.26. Contamination between 8 a.m. and 9 a.m., number of *contaminated nodes.*

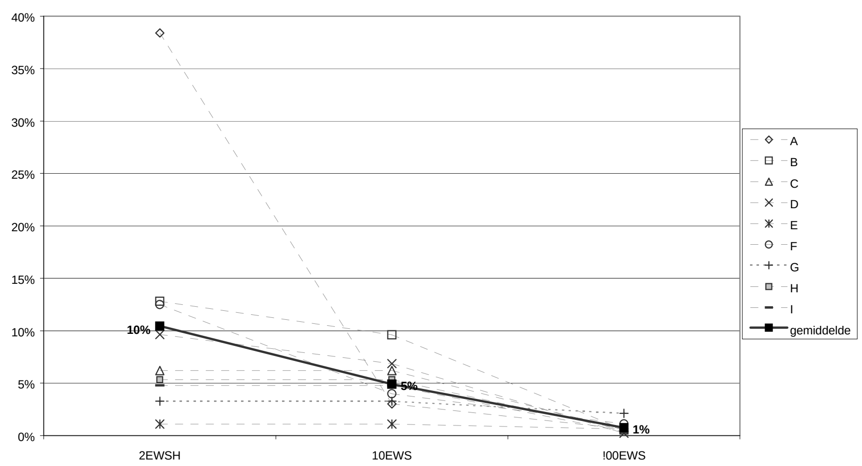


Figure 2.27. Contamination between 8 a.m. and 9 a.m., percentage *of total consumption contaminated.*

2.2.4 Discussion

The calculations using the model of town B were performed with the aim to establish the role an EWS can play in reducing the effects of intentional contamination of a drinking water supply system. Based on these simulations the following conclusions can be drawn:

- In principle, it is possible to introduce at toxic compound into a supply network when operating from a private residence without being discovered. The impact of such an act, and the theoretical protection offered by EWS is closely related to the site of introduction of the contaminant, the number and the locations of the installed EWS. Furthermore, the impact is dependent on the way in which the supply system is operated and its layout.

- The number of EWS installed, as well as their distribution throughout the network, is directly related to the achievable protection of the consumers. In the calculations on town B, a method is presented that describes the effects of the introduction of a toxic compound and the level of protection that can be offered by early warning. The level of protection is summarised in table 2.9.

Table 2.9. Relation between the protection offered and the number of EWS employed in the case-study on town B.

Number of connections per EWS	Total number of EWS in town B	Level of Protection
12,500	2 EWS	85 – 90 %
2500	10 EWS	90 – 95 %
250	96 EWS	approx. 99 %

- The response time of an EWS is essential for offering adequate protection. It has been shown that the impact of a contamination will be twice as big when detection takes 30 – 50 minutes instead of 10 minutes.

- The positioning of an EWS can be optimised using calculations taking into account the directions of flow within the network, as provided by hydrodynamic modelling software. In order to obtain a realistic flow pattern, the flow patterns should be modelled using a detailed model of the distribution system and at least one full 24 hour cycle should be modelled.

3 Relationship between the robustness of EWS and the response upon an alarm

To limit the spread of a contaminant, extremely drastic measures have to be taken once an EWS has detected a toxic substance. The current distribution networks in the Netherlands are not fitted with automatic valves, which means that it is not possible to shut down sections quickly immediately after detection. Switching off high-pressure pumps is the only action that is possible within a short time of detection. This will result in cutting off the water supply of an entire distribution area. As this is an exceptionally extreme measure, it will be necessary to set very high requirements for the robustness of the EWS and the signal transmission system (see box 1). It will be necessary, for example, to completely eliminate the possibility of sediments in the water ("brown water") being mistaken for toxic contamination.

<u>Box 1. Robustness of EWS</u>

Suppose that a density is chosen of 1 EWS per 250 connections. A water company sets the standard that, for every 100,000 connections, an erroneous report that results in the water supply being shut down is permissible once every 10 years. Four hundred EWS will be installed in this area. The robustness requirement means that no more than one erroneous report per 4000 years, per EWS is permissible.

Effect of the response time

This study demonstrated that a longer response time, the time between arrival of a contamination at the location where an EWS is positioned and switching off pumps, will result in an increase in the number of victims. With a density of 1 EWS per 250 connections, the number of affected connections could double for a response time of 30 minutes when compared to an EWS with a response time of less than 10 minutes. This means that systems that measure and respond immediately must be the preferred choice when selecting an EWS.

Actions following detection

The action taken after detection of a contaminant is to immediately switch off the pumps. It is only possible to remove the pressure from the network if connecting valves from reservoirs and coupling pipes are closed. To prevent the contamination's further distribution in the network, these valves must be remote controlled and must be switched off simultaneously with the pumps. Water could still come out of the taps in the case of level differences. In the event of opening a tap at a higher level, air would enter the network and water could be consumed at a point situated at a lower level. Water could flow from taps at a lower level for a considerable time, especially in hilly areas.

Particularly for larger networks, sectioning could be considered as a possibility for minimizing the impact of a terrorist attack and the time taken for the associated response, i.e. switching off the pumps. This could be dealt with proactively by confirming that the configuration of the present water mains system does not have an unnecessarily open structure, which allows contaminants to move readily through the water mains system. A reactive response would be possible by fitting controllable valves at strategic locations, which could be closed in the event of an attack.

Positioning EWS

Positioning EWS at the extremities of a water mains system increases the likelihood of detecting a toxic substance but also the likelihood of many people being affected. A location in the main structure means that it will be detected quickly, if the substance is injected upstream but will not be detected in the case of downstream injection. It will therefore be necessary to find a balance between installation in the main structure and installation at the edges of the distribution network. The flow directions that occur within the network are an extremely important factor in determining the effectiveness of EWS. Where unambiguous flow directions occur, the risks are fairly simple to determine using a water mains system calculation. High requirements will have to be set for the correct modelling of the water mains system in networks with interconnecting parts that have a carrier function or changing flow directions (such as in an area with an alternating flow or in the vicinity of a reservoir).

Future EWS placement simulations

The water mains system programme ALEID2002 was used for modelling the impact of positioning EWS throughout a distribution network. It was indicated that the calculated results are expected to underestimate the impact. Kiwa Water Research proposed a survey for the further study of consumption patterns of smaller groups of houses. Such a study would be required if a more accurate estimate is to be made of flow dynamics at the level of individual streets. This is required if EWS are to be placed and employed in an optimal fashion.

I Positioning of EWS in a distribution network

The importance of conducting a proper analysis of the distribution network to determine the exact location for an EWS is illustrated by the following example. Contamination is injected into the network between 1 a.m. and 2 a.m. (see Figure 1 the red nodes). The EWS is in node 1VN03003 on the right of the figures. In Figure 2, the contamination moves towards EWS. By 18:50 hours the contamination (see red nodes) has moved to just in front of the EWS. Detection will not occur because the water of the node with the EWS flows towards the contamination.

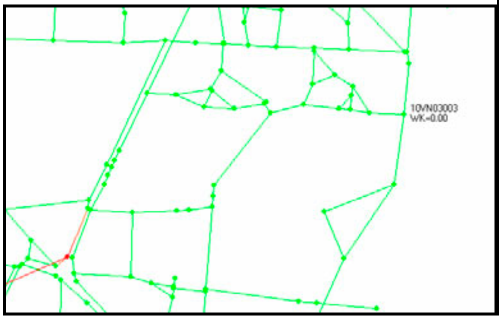


Figure 1: 01:20 hours

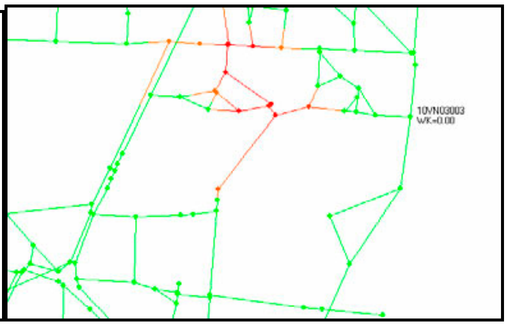


Figure 2: 11:00 hours

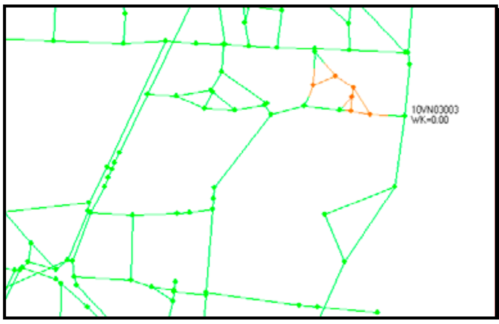


Figure 3: 18:50 hours

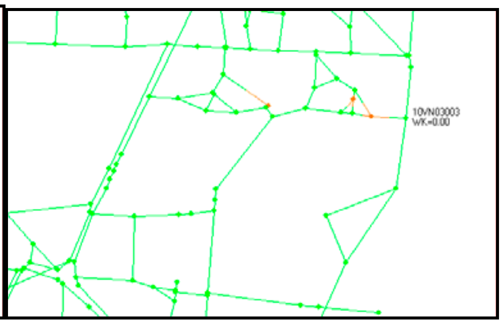


Figure 4: 24:00 hours